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Comparative evaluation of renewable energy scenario in Ghana

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Abstract. Availability of cheap, reliable and safe energy is very essential to the growth and development of every nation. This paper assesses solar radiation and wind speed at one site each in the southern, middle-belt and northern part of Ghana to estimate the potential of integrating solar and wind energy into the country's energy mix. The analysis included the financial viability of a possible 2.5 MW installed solar power plant in Gomoa, Kintampo and Navrongo. The RETScreen software was used for the feasibility and financial viability evaluation. The study found out that the southern part of the country experiences the least solar irradiation as it recorded 4.73 kWh/m2/day, the middle belt recorded 5.28 kWh/m2/day, the northern belt however recorded the highest level of solar irradiation of 6.07 kWh/m2/day. It was also found out from the research that the southern belt has the highest annual average wind speed of 2.8 m/s followed by the northern sector with 2.3 m/s and the least was recorded in the middle-belt with an average wind speed of 2.2 m/s. The financial indicators like the internal rate return, equity payback years, cumulative cash flows and simple profitability index all indicated that the northern sector is the best site for the development of solar energy although the other parts of the country are also positive. The impact of the development of these plants will also have a considerable impact on the environment since the research shows some 93% reduction in the emission of greenhouse gases (GHG).

1. Introduction

Renewable energy has recently drawn significant attention from policy makers and researchers around the world as a result of it environmentally friendly nature. The world is now moving towards reliable and feasible hybrid renewable energy because of the depletion of fossil fuel and the negative effect on the environment as well as the potential technoeconomic merits of hybrid combinations [1]. The share of renewable energy in the world is expected to increase from 19% in 2008 to about a third in 2035 [2]. Ghana is expected to increase it share of renewable energy in the total installed capacity to 10% by 2020 [3]. Solar and wind energy largely depends on the climatic conditions in a particular location, they depend on the availability of sunshine and wind flow respectively [4].

It is very important in the renewable energy sector to conduct feasibility studies before implementing a project. Several computer tools are used in analyzing renewable energy, some examples are the HOMER and the RETScreen software [5]. Ghana is confronted with energy crisis as a result of high cost of fuel to power the thermal power plants It is therefore important to give a boost to Ghanaian energy policy by increasing the percentage of renewable energy sources in the country's energy mix to drive down the high cost of energy generation and to build a climate friendly environment for the future. This requires considerable research, planning and development to help integrate renewable energy into the existing transmission and distribution system [6,7]. This paper investigates the feasibility and financial viability of solar and wind energy Ghana to ascertain the best site for renewable energy generation.

2. Overview of electricity generation and usage in Ghana

The total installed electricity generation capacity available for distribution at the transmission level in the country as in 2017 was about 4310 MW according to the 2018 Energy Commission Report. If the embedded generation including the two major solar power plants at the distribution level is added, the total installed capacity increases to 4398.8 MW. Ghana's total grid-electricity generation including the embedded generation was 14069 GWh, this consist of 69.3% thermal including projected total generation, 30.40% hydro and about 0.3% solar power. The grid electricity at transmission level including imports was around 14309 (±1%) GWh consisting about 5616 GWh (39.2%) from hydro, 8373 GWh (58.5%) thermal and about 320 GWh (2.2%) of import.

The peak load (domestic peak load) on the transmission grid without export in 2017 was 2,077 MW, which is roughly 4% more than in 2016 whiles the peak utilized on the transmission grid was 2,192 MW 6% more than in 2016. Figure 1 shows the current energy generation [8 - 10].

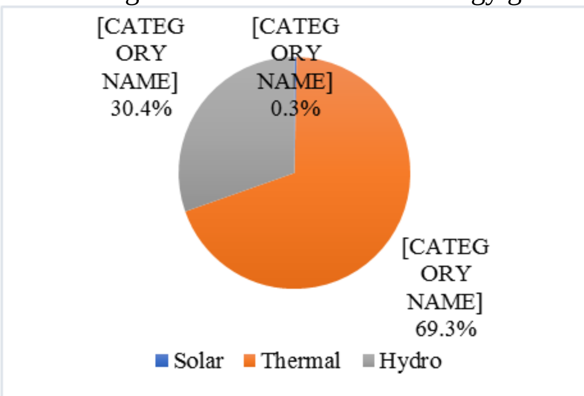

Figure 1. Power generation mix.

3. Energy planning

A comprehensive energy system analysis is aimed at ensuring a good energy-related policy and to enable investment decision [11]. Planning increases the nation's capacity to anticipate and respond to changes and opportunities arising in the sector. Planning extends beyond borders particularly in the case of developing countries with huge energy potentials, example renewable energy. Like other instances of public energy policy, it has been informed mainly by recourse to analytical models [12]. Energy modeling is key in the energy sector, it happens to be data intensive which is a challenge for several countries [13].

3.1 .Methodology and materials used for the analysis

The aim of this research is to access the renewable potential of Ghana using the software RETScreen. The modeling was done using the following methods: selection of the locations and evaluation of the energy potentials of the area and using the RETScreen to do a detail assessment of the economic value of the results. A polycrystalline solar cell was selected for this research with other parameters as shown in table 1. The solar panel used in this research is fixed system tilted at an angle of 45°. The research used the characteristics of the nation's 2.5 MW Navrongo Solar Power Plant (SPP) located at Navrongo with an inflation rate of 9% for 25-year lifetime. It is sited on 4.77 hectares of land and has an expected annual generation of 3.7 GWh [14, 15]. Figure 2 shows the map of Ghana divided in three sectors for the modelling process. Figure 3 is the solar power plant situated in Navrongo in the northern part of the country.

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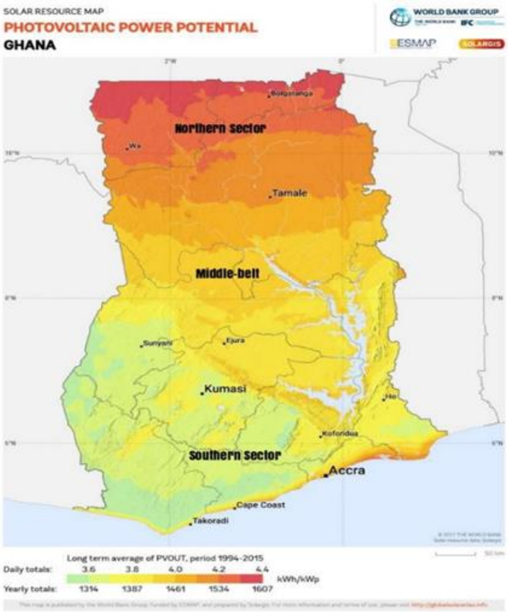

Figure 2. The map of Ghana showing the various sectors.

Figure 3. Navrongo solar power plant [15].

Three sites were selected across the country, namely Navrongo in the Upper East region in the northern zone located on latitude 10.90° N and longitude -1.10° E this is the site which currently host the largest solar power plant (SPP) of the country. Kintampo in the Bono East region which is located in the middle – belt located on latitude 8.05° N and longitude -1.73° E and Gomoa in the southern part of the country located on latitude 5.41° N and longitude -0.74° E.

Table 1. Electrical and physical characteristics of the PV modules used in all scenarios [16].

Electrical characteristics	
Plant Capacity	2.5MW
Expected Annual Generation	3.7GWh
Photovoltaic Panel	
Number of Modules	8,622
Type	Polycrystalline
Maximum Power (STC)	295Ww
Open Circuit Voltage	45.1V
Short Circuit Current	8.57A
Module Efficiency	15.2%
Module Dimensions	1956 x 992 x 50mm
Weight	27 kg
Inverter	
Manufacturer	Guanya Power
Rated Output Power	500kW
Maximum Efficiency	>97.5%
Maximum DC Input Voltage	900V
MPPT Voltage Range	440-850V

4. Results and discussion

The southern sector of the country covers five regions of the country, these includes the Greater Accra, Central, Eastern Volta and the Western regions. It has an annual average solar irradiation of 4.73

kWh/m^2/day and average wind speed of 2.8 m/s. From the analysis, the initial cost of the Solar PV system was found to be $7,501,140 for all three scenarios. The gross annual GHG equivalence obtained from the simulation was found to be 735.7 tCO_2 134.7 which represents about 93% annual reduction in GHG emission for the southern sector. Sections of the southern sector are considered good potential for wind energy generation. A minimum wind speed of 2.4 m/s for the southern sector is usually recorded in June whiles a maximum of 3.2 m/s occurs in August when the rainy season is at its peak.

The middle-belt also includes the Ashanti, Oti, Brong Ahafo, Bono East and the Ahafo regions. The obtained annual solar irradiation in this area is 5.28 kWh/m^2/day and an annual average wind speed of 2.2 m/s. The minimum wind speed of 2 m/s occurs in the dry season whiles the maximum occurs in the rainy season at a speed of 2.5 m/s. The gross annual GHG equivalence obtained from the simulation for the middle-belt was found to be 831.9 tCO_2 152.4.

The northern sector covers the Northern, Savannah, North-East, Upper East and the Upper West regions. This area experiences the highest direct solar irradiation, an average of 6.07 kWh/m^2/day annually with an annual average wind speed of 2.3 m/s. The maximum wind speed of the area is recorded in the month of May with a speed of 2.7 m/s whiles the minimum is recorded in October at a speed of 1.9 m/s when the harmattan begins. It also recorded the gross GHG emission as 971 tCO_2. Figure 4 – 12 illustrates the weather data, cumulative cash flow and the equity pay-back analysis.

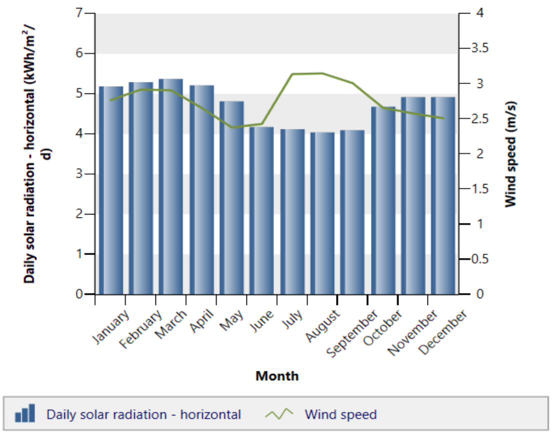

Figure 4. Climate data for the Southern Sector (Gomoa).

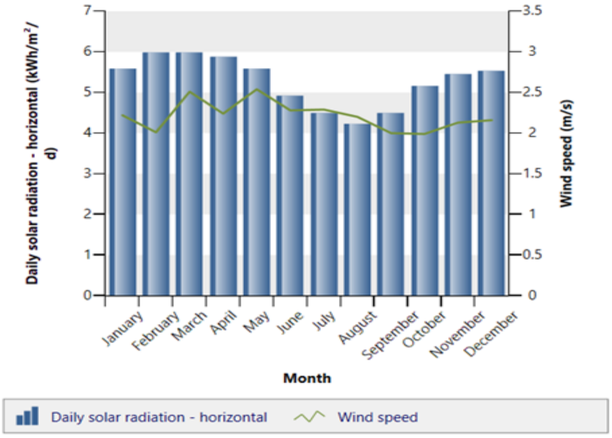

Figure 5. Climatic data for the middle belt (Kintampo).

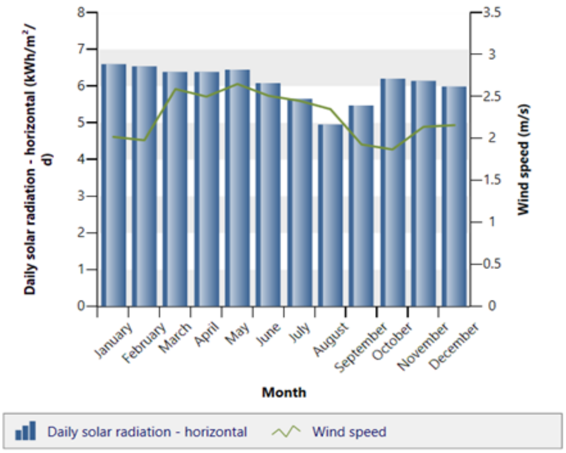

Figure 6. Climatic data for Northern belt (Navrongo).

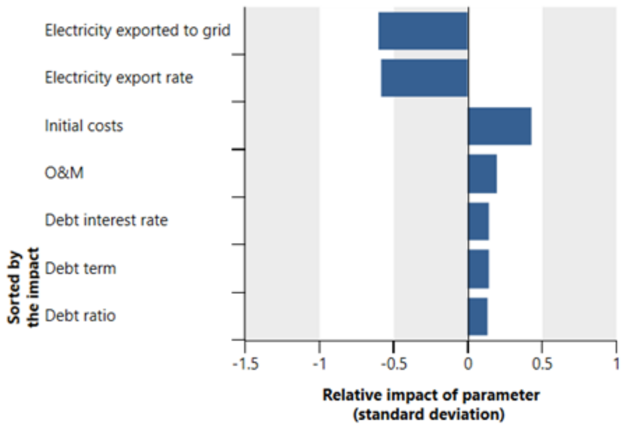

Figure 7. Risk – Impact (Equity payback) for the southern sector.

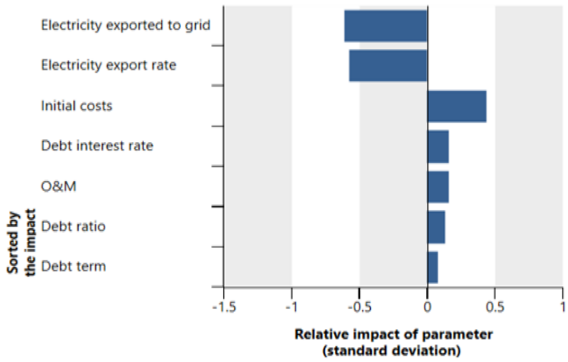

Figure 8. Risk – Impact (Equity payback) for the middle – belt.

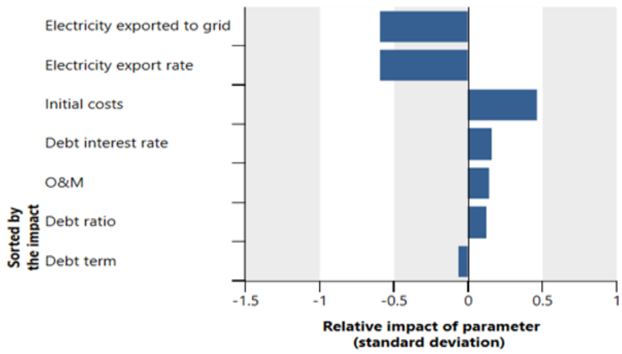

Figure 9. Impact (Equity payback) for the Northern belt.

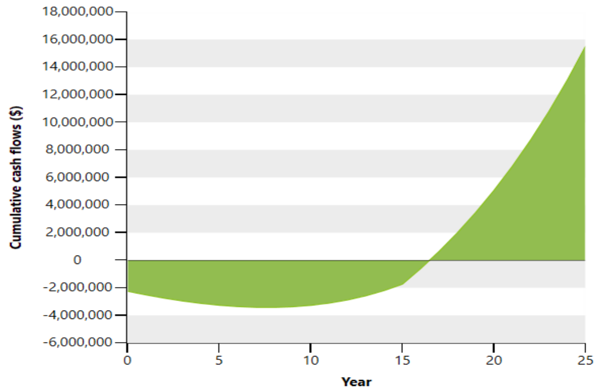

Figure 10. Cumulative cash flow for the middle-belt sector.

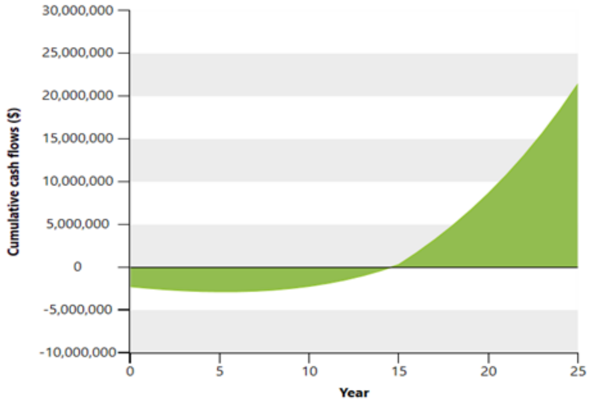

Figure 11. Cumulative cash flow for the Northern -belt sector.

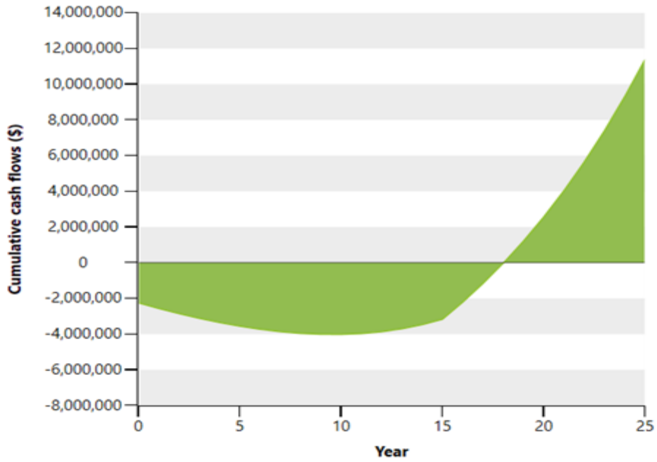

Figure 12. Cumulative cash flow for the southern sector.

It is important to note that the renewable energy technology is capital intensive with zero fuel cost unlike the traditional technologies in which the cost of fuel is higher relative to renewable energy, hence the need to evaluate the economics of the technology before investment. In the first scenario (southern sector), the equity payback was 18 years after construction and had an internal rate return (IRR) asset of 2.6% and the case of the second scenario (Middle – belt), the equity payback period was

16.5 years with an IRR asset 4%, the third scenario (Northern – belt) recorded the least equity payback of 14.5 years and an IRR asset of 5.8%. Comparative analysis of the various projects relative to their financial viability is summarized in Table 2.

Table 2. Financial viability and savings for the three scenarios.

	Southern sector	Middle-belt	Northern sector
Initial cost (100%) $	7,501,140	7,501,140	7,501,140
Annual costs and debt payments			
O&M cost (savings) $	100,015	100,015	100,015
Debt payments – 15years	576,509	576,509	576,509
Annual savings and revenue			
Electricity export revenue, $	341,506	386,181	450,746
Electricity exported to Grid, MWh	3,415	3,862	4,507
Financial viability			
Pre-tax IRR equity, %	7.4	9.5	12.2
Pre-tax IRR assets, %	2.6	4	5.8
Simple payback, years	31.1	26.2	21.4
Equity payback, years	18	16.5	14.5

The development of a solar PV project would be adequate if IRR is equivalent to or greater than the required rate of return. From table 2, it is seen that the IRR is directly proportional to the amount of solar irradiation. The maximum IRR of 12.2% is found in the northern sector where solar radiation is high while the minimum of 7.4% is found at the southern sector with the least solar radiation. Generally, all three scenarios are commercially viable

5. Conclusions

This paper investigates the effectiveness of construction of photovoltaic power plant in Ghana, it assessed the feasibility and cost effectiveness for three different sites. The sensitivity analysis shows that the success of a PV plant is dependent on the weather conditions available at the site. From the analysis we realize that the third scenario (Northern sector) which is in a hot-arid region, is the most viable for SPP project. However, the southern sector has the highest potential for wind energy since it has comparatively higher wind speed. Construction of such projects will drastically reduce the emission of GHG into the environment.

The study is still at its incubatory stage and requires further evaluation in the following areas: conductions of similar analysis in the case of wind and hybridizing them, analysis of renewable energy sources and their impact on smart power systems and an experimental analysis with a considerable volume of data.

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